



Technical Paper

Holonic control approach for the “green”-tyre manufacturing system using IEC 61499 standard



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ABSTRACT

Traditional tyre-manufacturing systems are characterised by a slow response during optimisation of the manufacturing process and insufficient adaptability to system disturbances. The objective of our research is to develop a distributed and adaptive control approach based on the concept of holonic control and IEC 61499 function blocks. A brief description of the manufacturing modules within the “green”-tyre manufacturing system is given. The architecture of distributed holonic control and implementation environment using IEC 61499 function blocks are then proposed and elaborated. Comprehensive discussion is given thereafter, including an evaluation of the distributed holonic control approach within the virtual manufacturing environment based on simulation tests for various scenarios, whereby system operation in unstable conditions is taken into account. The real-life implementation of this technology in the future is expected to increase productivity, resource utilisation and robustness in a tyre-manufacturing environment.

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1. Introduction and problem statement

Tyre-manufacturing systems are faced with an increasing number of various tyre types and sizes, while the tyre market circumstances are variable and uncertain, which increases the complexity of manufacturing processes and manufacturing systems. Consequently, there is a growing need for agile and adaptive solutions in the field of designing manufacturing systems. New solutions would reflect a dynamic response to changes and disturbances within the manufacturing environment. An ideal manufacturing system would achieve optimal performance in real time in a stable as well as unstable environment. In an unstable manufacturing environment, traditional control approaches are inflexible, time consuming and prone to faults when directly implemented into a dynamic manufacturing environment.

Control architecture of most tyre-manufacturing systems are centralised and based on conventional industrial control devices – programmable logic controllers which control the lower levels in a control structure including control of actuators based on sensor data. The software environment within the centralised control structures is designed as a group of pre-defined software units.

Development of a software environment within programmable logic controllers requires development of monolithic software procedures. These are difficult to change and expand due to the use in new applications or connection to software environments which are designed on various platforms. The adaptability of centralised control systems to unpredictable changes in the system is insufficient due to the monolithic nature of the software procedures within programmable logic controllers. A suitable solution which will enable an appropriate response to such changes is development of a distributed and adaptive control system which will be organised as a group of cooperative units and will not include a master controller in the control structure. This control system will enable the manufacturing system to achieve optimal performance in a dynamically changeable manufacturing environment.

Our approach will be based on IEC 61499 function blocks and the concept of a holonic control structure. The IEC 61499 standard of function blocks is an upcoming framework for the design of distributed control applications of industrial manufacturing systems [1].

The original concept of function blocks is presented in the IEC 61131-3 standard, which defines the standard language for programming programmable logic controllers. Applications developed in accordance with the IEC 61131-3 standard cannot be distributed to several different resources, which presents a restriction for the development of distributed control applications. In complex control systems, however, it is very difficult to determine the order of control functions performed.

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The IEC 61499 standard defines the reference architecture of distributed control systems and methodology of describing function blocks in a form which is independent of the implementation method. The standard also defines the type of communication function blocks which are used for data exchange between the resources found on various devices. Furthermore, the standard determines the design of service interface function blocks (SIFB) which maintain a connection to smart field devices (e.g. autonomous mechatronic components with embedded microcontrollers). As a general standard, the IEC 61499 standard does not define specific features of particular industrial applications and communication protocols [2]. Implementation of an event-driven model of function blocks, communication protocols and appropriate smart field devices will make this system more autonomous and agile in the phase of adapting to changes in the manufacturing environment. The control structure will be defined by interconnections of function blocks and software agents.

The objective of this study is to develop an environment for implementation of distributed holonic control approach within the tyre-manufacturing system by means of function blocks. Since function blocks enable detection of changes in the manufacturing environment, the use of function blocks within the distributed holonic manufacturing system (DHMS) is expected to enable the dynamic response in the case of new optimisation demands and decrease the impact of disturbances and faults on production productivity. A significant step towards practical implementation of control applications which are based on holonic control structures is the development and verification of lower levels in the control structure. Lower control levels are dealing with the connection to real or virtual machines in the manufacturing environment. Our approach will contribute to this objective.

After the initial analysis of the actual problem (Chapter 1) and an overview of the current situation in this field of interest (Chapter 2), the paper will continue with a presentation of the properties of the tyre-manufacturing system (Chapter 3) followed by a description of the distributed holonic control architecture by means of function blocks at the lowest architecture level (Chapter 4). Development of function blocks within the presented architecture and environment for their implementation in a real or virtual manufacturing system will be presented in Chapter 5. Chapter 6 will include evaluation of the presented control approach within a virtual manufacturing environment.

2. Background – literature review

In the field of automation of industrial production systems, the holonic control approach has attracted a lot of attention due to its distributed nature and ability to adapt to disturbances in production systems. A few studies in this field [3–6] discuss implementation of general agents within which agent behaviours are executed only in the simulation environment. As evident from studies on real-life implementation [7–10], in most cases multi-level control architectures are used. Different agent behaviours at higher levels of multi-agent architecture are performed on separate computers, while lower levels are still implemented within programmable logic controllers. To facilitate integration of the holonic control system with the physical system, the logic structure of the physical system must be mapped into the logic structure of the control application.

With the purpose to implement the distributed control approach into industrial systems, development of event-driven function blocks within the IEC 61499 standard has been made. IEC 61499 function blocks present an extended version of function blocks based on standard IEC 61131-3. Among commercial tools used for development of control applications in accordance

with the IEC 61499 standard, the following tools are considered most important for the industrial environment: Functional Block Development Kit (FDBK) [11], which originates from the HMS project [12], ISaGraph [13], ntxControl [14] and 4DIAC [15]. To make the IEC 61499 standard applicable on various hardware devices, the manufacturers of such devices must develop support for the standard. The possibilities of implementation on industrial devices are currently limited since there are only few platforms for direct execution of function blocks within the industrial devices, including the ElsisNetmaster II platform [16] and the Tait Control Systems Intelligence platform [17]. Furthermore, researchers must develop new software approaches and architectures which will enable implementation of the DHMS into the industrial environment. Even though researchers have in the last period developed many control applications based on the IEC 61499 standard, they were mostly limited to a lower control level and were not able to resolve reliability issues resulted from system disturbances. In our control structure, this deficiency is being addressed at higher control levels by means of the holonic control concept. Olsen et al. [18] presented implementation of a distributed control approach by means of a Java-based platform. The control application consists of IEC 61499 function blocks with the purpose of researching the system in the case of reconfiguration changes in the system. Hussain and Frey [19] presented modelling of a flexible and reconfigurable application based on the IEC 61499 standard. The control application was implemented as part of the NETMASTER network controller. The IEC 61499 standard proposes approach of hardware independent modelling of control applications which is similar to the concept of the model-driven architecture (MDA). The MDA concept [20] proposes separating the logic control domain from the hardware domain. The concept describes the system by means of various models. Models defined by the MDA concept are: Platform Independent Model (PIM), which defines the logical functionality of the control application and as such does not include any specific platform technology; Platform Description Model (PDM), which describes the platform or hardware that the control application will be used on; Platform Specific Model (PSM), which describes the use of the platform technology and services provided by this platform. In the field of control structure development, several studies have been performed by means of the MDA concept [21–24]. In our study, we will use an approach which is based on hardware abstraction (Hardware Abstraction for IEC 61499 [21]) and presents an upgrade of the MDA concept. This approach will help decrease the complexity of the process of distributed control structure development and enable its implementation on various machines with minimal redesign activities.

The connection between the holonic approach and function blocks was first presented by Fletcher [25]. His studies have shown that the technology presented in the IEC 61499 standard is suitable for decentralised control application under the holonic approach. Within the framework of the HMS project, Christensen [26] presented the use of function blocks which are integrated with the holonic control approach already in the initial phase of the control application design. The control architecture was divided into two domains: low-level control and high-level control. The purpose of the low-level control is to perform control and automation functions by means of function blocks implemented in accordance with the IEC 61499 standard. High-level control, however, includes coordination and cooperation functions regulated by FIPA standards. For this purpose, holons or multi-agent structures were used. Wang et al. [27] described the control architecture, which enables distributed and intelligent control in real time and combines the IEC 61499 standard of distributed control with the holonic control paradigm. They also presented the generic control system, which will control the lowest level of control architecture. Vrba [3] presented the architecture for simulation of production systems which

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